OCT 4 1928

Volume X OCTOBER, 1928 Number 8

Medical Lib.

THE JOURNAL OF INDUSTRIAL HYGIENE

AND ABSTRACT OF THE LITERATURE

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The Method of Action of Silica Dust in the Lungs

The Gravimetric Determination of Dust Inhaled by Workmen

Published at Mount Royal and Guilford Aves., Baltimore, Md.
by HARVARD SCHOOL OF PUBLIC HEALTH

Entered as second-class matter, at the Post Office at Baltimore, Maryland, under Act of March 3, 1879.
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THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME X OCTOBER, 1928 NUMBER 8

DEVELOPMENT OF INDUSTRIAL HYGIENE IN CANADA*

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INDUSTRIAL hygiene, as a deliberate and self-conscious movement to make man's physiologic requirements the criterion upon which working conditions are based, is not quite a decade old in Canada. Before that time, the only bodies definitely concerned with the safeguarding of the health of industrial workers were the labor departments of the different provinces, which through their factory inspection branches enforced factory legislation. At the present time these departments are still responsible for law enforcement, and accordingly for the enforcement of such industrial hygiene measures as have been incorporated in legislation. As will be seen later, these measures are for the most part embodied in the general Factory Acts and concern general hygienic control of working conditions, covering such points as hours, age of employment, ventilation, sanitary facilities, provision of seats, etc. But the modern movement in Canada for the study and promotion of industrial hygiene, as defined above, is a definite offshoot of the British Health of Munition Workers Committee, which, as the result of the urgent war time need of simultaneously increasing output and conserving man power, had been established in England to study industrial physiology—to find out, that is, the sum total requirements of workers *with* which their health, energy, and output are at their highest, but *without* which there is waste through ill health and fatigue.

It was, then, the emergency of the war which produced realization of the central principles of industrial hygiene —the principle that output and health are integrally related, and the principle that health reacts delicately to all factors in working environment. Thus, it is the aim of industrial hy-

* Received for publication April 20, 1928.

giene, first, to find out, frequently only by long and intensive research, precisely what the ill effects of industrial processes are, and, second, to promote the prevention or minimization of these ill effects. Thus the bodies which have been organized for the promotion of industrial hygiene are concerned with the discovery and extension of optimum conditions of work, while labor or other government departments charged with law enforcement are administering such industrial hygiene measures as have already been formulated as minimum requirements and, as such, incorporated in the laws of the land.

Committee on Industrial Fatigue

It was the reports of the Health of Munition Workers Committee which led to the establishment in Canada in 1919 of a federal Committee on Industrial Fatigue, which was formed under the Honorary Advisory Council for Scientific and Industrial Research and was chiefly composed of the leading physiologists of the various Canadian universities.

The Committee, which, as its name implies, had been at first conceived of for the study of industrial fatigue, early realized that such study in Canada would be premature, and must of necessity be preceded by a widespread and intensive campaign for the study and promotion of the more elementary principles of industrial hygiene. In consequence, during its year and a half of active existence, the Committee concentrated on the preliminary work of studying existing health conditions in Canadian industry, of establishing liaison with industrial health agencies both in Canada and elsewhere, and of building up a valuable reference library and information bureau on all aspects of industrial hygiene. In addition to general propaganda and publicity, it published a survey of general conditions of industrial hygiene in Toronto during 1920,[1] a document the chief interest of which today is as an index of the growth of the movement since that time. The chief office of the Committee was in Toronto, the attempt to establish a similar branch in Montreal having failed. In view of the Committee's early recognition of the fact that the study of industrial fatigue in Canada presupposed a previous widespread promotion of industrial hygiene, the actual developments as existing today seem right and inevitable.

After a year and a half of active service, functioning in Toronto, the Committee on Industrial Fatigue went into abeyance, its staff, equipment, and library being taken over by the Ontario Department of Health, which, on the impulse from, and with the nucleus provided by, the Committee, instituted the Division of Industrial Hygiene for the promotion of industrial hygiene in Ontario. The Division has been working for seven years and during the past year a somewhat cognate development, but from a different angle, has occurred in the Province of Quebec, a division of industrial hygiene having been formed in the Public Health Department of McGill University. Thus, the preliminary objectives of the Committee on Industrial Fatigue are

[1] Survey of General Conditions of Industrial Hygiene in Toronto. Associate Committee on Industrial Fatigue. Honorary Advisory Council for Scientific and Industrial Research, Rep. No. 7. Ottawa, 1921.

at present being served from two major foci—a government department in Ontario, and a university in Quebec. Presumably further developments in other provinces—bound eventually to come in the course of general progress—will be either stimulated or retarded by the achievements of these two bodies.

Division of Industrial Hygiene

In Ontario, the Division of Industrial Hygiene has concentrated on three major lines: (1) the carrying on and extension of the Committee's reference library and information bureau, together with a limited amount of propaganda and publicity work, such as articles in scientific and medical journals, trade and labor papers, and the daily press; (2) the promotion of medical service in industry; (3) the study and control of occupational diseases. In all these activities, the policy has been to co-operate with employers, to provide the data by which local conditions can be assessed and evaluated, to make the scientific research of other countries readily available and applicable, and to co-operate with industry in those cases where the equipment of the Division is required for specific research and investigation.

Development of Medical Service in Ontario.—Slowly and gradually medical service is spreading in Ontario. While plants that are big enough to employ full time physicians are few, the basic principle of medical supervision—that is, the policy of employing a physician, whether full time or part time, to be responsible for the health experience of the plant—has made considerable headway. The biggest and most influential plants in Ontario either have already established such a service or are on the verge of doing so. At the same time, and as corollary, the practice of keeping detailed records of lost time from sickness has increased, and various plants are now regularly supplying the Division with valuable tabulated data. At Thorold, there is an interesting instance of small plant co-operation, where, as a development of the initial experimental demonstration carried out by the Division, four small plants, of which the largest has only 300 employees, have amalgamated to provide medical service for the employees. At the same time, the number of industrial nurses is steadily increasing. The phase of medical service in which most rapid progress is being made, however, is physical examination. In the 1920 survey of the Committee on Industrial Fatigue, it was stated that physical examination existed only in four public services, and that the most that could be said of private plants was that the project was vaguely in their minds. Today physical examination is in force in all public utilities and in many of the largest plants, including all the big storage battery plants. At the moment, it is being furthered by the insurance companies so that the influential lead given is sufficient to secure its further extension. Annual physical examination has also been established by law in the different camps of the mining industry. Among granite cutters, it is at the moment under consideration. In these three instances, storage batteries, mines, and granite work, the movement arises out of investigations

by the Division which proved that occupational hazards existed.

In Northern Ontario a very interesting situation exists. The attempt to provide medical facilities in unorganized territories has developed into a system whereby every employer is bound by law to contract with a physician for the medical treatment of his men at so much per man per year. Such a system approximates to the Chinese method whereby it is to the physician's benefit to keep people well, and, as a result, a system of preventive medical service is growing up and should become yearly more firmly established and more effective. Where the physician is immediately and vitally concerned in keeping down all possible sources of ill health, and where all the plants in the neighborhood are on a similar system with regard to medical service, so that there is unusual basis for comparison of results, industrial hygiene in all its many sides has an admirable chance of being put to the test. While the full opportunity offered has not yet been seized, undoubted progress is being made, and that the system is a good one and workable may be judged from the fact that Manitoba and Quebec have modeled on the same lines their legislation governing sparsely settled territories where the main activity is industrial.

Study and Control of Occupational Diseases.—In the study of occupational diseases, the Division works along two parallel lines. First, it carries on general investigations into certain industries, selected because of their known dangers, and makes special, long period study of industrial problems common to all industries. Second, it conducts smaller, more defined investigations of the specific problems which are continually being referred to it, either by the plants themselves or by other bodies and associations concerned. In many of these cases, the laboratory equipment of the Division is essential and affords small plants their only facilities for scientific investigation of their problems.

On the general line, investigation into the incidence of lead poisoning disclosed the existence of serious danger, and preventive measures have been established where required. The worst situation existed in storage battery plants and all these have now appointed physicians to supervise the health of exposed workers. The data from these plants will be a useful contribution to the Division's study of the diagnostic value of basophilic red cells in the blood. Again, investigations in Northern Ontario established beyond doubt that silicosis was being produced in Ontario mines; as a result, annual physical examination has been established and silicosis, as defined in South African legislation, when contracted in mining is now compensable. The hazards of granite cutters are at present a subject of study and it is likely that physical examination will shortly be conducted in that industry also. The diseases which have been made compensable, following work by the Division, are silicosis in mining, stone workers' or grinders' phthisis in quarrying, etc., and benzol poisoning in any process involving the use of benzol.

In compressed air work, the Division's investigations preceded the enactment of legislation safeguarding

the industry. While the amount of work being done in compressed air has greatly increased, the number of cases of caisson disease has remarkably diminished and those that do occur are very mild.

Similar problems on which the Division has concentrated are nickel poisoning and poisoning from arsenic trioxide in the smelting of ores. For some time now a special study has been in course on various aspects of the ventilation problem, both in certain industries, especially those where hot processes are a feature, and in schools.

From the foregoing, it will be seen that the Division's policy in regard to occupational diseases is to concentrate efforts on those that are found to be working havoc, to promote prevention by the most fundamental and wide-reaching methods, such, for example, as the establishment of physical examination and medical supervision, or by scheduling the disease as compensable, and at the same time to conduct investigations into certain of the scientific problems involved which have not been otherwise solved. In addition, smaller and localized problems are dealt with as they are referred to the Division, in some cases merely by putting the applicant in possession of the latest information on the subject, in others by investigation and laboratory study. Now that so much of the Division's time is in demand for the combating of occupational diseases, it is interesting to recall the aforementioned initial report on industrial hygiene in Toronto made in 1920. On the subject of occupational diseases, the following passages occur:

> Data on the extent to which occupational disease is a problem in Toronto is exceedingly scarce. . . . . The statements of private practitioners, industrial physicians, and clinicians in the wards and outpatient clinics of city hospitals all seem to indicate that specific occupational disease is not a problem in Toronto, and this is borne out by the experience of the Workmen's Compensation Board. On the other hand, however, even in the course of the very general survey of a limited number of plants made for the purpose of this report, instances of specific occupational disease were encountered. . . . . On the whole we are forced to the conclusion that there is general lack of recognition of the occupational factor in disease.

Today it can at least be said that such lack of recognition is considerably less prevalent, and that the most outstanding occupational diseases are under observation and have been diminished. At the same time, very much still remains to be done.

Industrial Hygiene Division, McGill University

In Montreal, a most excellent start in industrial hygiene, and one that seems exceptionally full of promise, has been made in the creation of the Industrial Hygiene Division of the Public Health Department of McGill University. The activities of this Division are of three kinds: (1) hospital; (2) university; and (3) field.

Hospital.—The industrial clinic, operated in the outpatient department of a large, down town hospital, studies patients whose work is in certain dangerous trades. In addition, a study is being made of industrial accident cases in the outpatient department, with special reference to infection.

University.—Courses of lectures in

industrial hygiene are being given to undergraduates, graduate nurses, social service workers, and graduate physicians.

Field.—Medical service, consisting of initial and periodic examination, treatment of accidents and minor illness, visiting nursing, and plant inspection, is being offered to industrial establishments. Plans also are on foot for a special study of some one hazardous industry.

Legislation

On the legislative side, throughout the provinces, general measures for the protection of health are incorporated in the Factory Acts and administered through factory inspection departments. There are no factory medical inspectors. The danger point in most industries, dust, is thus regulated by a general clause directing that "the air of workrooms be kept reasonably free from gas, etc." and discretion is left with the factory inspectors as to what is "reasonable" and how dangerous amounts are to be kept down. Apart from such general control, legislation directly bearing on industrial health, such as exists in other countries, is very scanty in Canada.

1. Laws governing dangerous trades in detail, usually providing for some form of medical supervision.—The only legislation on this is in Ontario where there are laws governing mining and compressed air work.

2. Laws for the reporting of occupational diseases.—No province in Canada has any such law.

3. Laws for the compensation of occupational diseases.—Occupational diseases, variously scheduled, are compensated in Alberta, British Columbia, Manitoba, New Brunswick, Nova Scotia, and Ontario. No compensation is allowed in Saskatchewan, Quebec, and Prince Edward Island.

4. Laws giving especial protection to women and children.—Except for clauses in general Factory Acts prohibiting the employment of women and children in certain dangerous processes, usually those concerned with dangerous machinery, Canada has no legislation on this point.

British Columbia is the only province with a maternity protection law, forbidding employment of women for six months after confinement and giving them facilities before confinement and while they are nursing their children.

5. Minimum wage laws for women.—Probably no one thing has so much bearing on health as adequate wages. Minimum wage legislation for women has been enacted in Alberta, British Columbia, Manitoba, Ontario, Saskatchewan, Quebec, and Nova Scotia and is in force in all provinces save the last. Similar legislation for boys exists only in British Columbia.

INHALATION EXPERIMENTS WITH CERTAIN LACQUER SOLVENTS*

HENRY FIELD SMYTH, M.D., DR. P.H.

AND

HENRY F. SMYTH, JR., B.S. IN CH.E.

THE composition of nitrocellulose lacquers as generally used is quite complex and the simplest of them contains at least several volatile solvents or diluents. A questionnaire sent out in 1925 by the Pennsylvania Department of Labor and Industry (1) brought replies from seventeen lacquer makers listing from two to eleven different volatile materials in each of their lacquers. Butyl acetate was reported in 11 lacquers, benzol, ethyl acetate, butyl alcohol, and toluol in 9, xylol and amyl acetate in 8, ethyl alcohol or denatured alcohol in 7, some form of petroleum distillate as gasoline, etc., in 4, and acetone, amyl alcohol, and other substances in others.

The toxicity of benzol and the menace to health from its use in spraying lacquers has been clearly shown by the Benzol Committee of the National Safety Council (2) and by the Spray Painting studies of the National Safety Council and of Pennsylvania (3) (4), but of the effect of many of the volatile solvents or diluents on the health of the sprayers little of definite nature is known.

Bearing this in mind, the Pennsylvania survey, under the senior author's direction, made some preliminary toxicity tests on guinea-pigs by exposing them in Yant and Frey gassing jars (5) to the vapors of two of the above-mentioned solvents and the authors have since then made similar tests with all the others, except benzol, that were reported as present in five or more lacquers in the Pennsylvania questionnaire, as well as with one type of turpentine, a solvent sometimes found in the newer, less rapidly drying brushing lacquers. They also included distillates obtained from a spraying and a brushing lacquer, both free from any but small amounts, less than 0.5 per cent. of benzol.

The present paper aims to summarize the results of these tests as they bear on the possible toxicity of each of the substances tested, the concentrations in which it may be safely used in a lacquer, and the effect of lacquer solvents in general on the health.

Keyes (6), in an article on lacquer components, divides the usual fluid components of lacquers into four groups, based primarily on their boiling ranges, as follows: (1) Low boilers, boiling below 100°C., with benzol as the type. In this group are found, among others, ethyl acetate and ethyl alcohol of the solvents mentioned

* Received for publication March 23, 1928.

above. This group usually comprises 10 to 25 per cent. of the liquid portion of spraying lacquers. (2) Medium boilers, boiling near 125°C. and including toluol, amyl acetate, butyl alcohol, and turpentine of the foregoing list, although Keyes does not mention the last. They usually comprise 20 to 45 per cent. of the liquid content of spraying lacquer. (3) High boilers, boiling from 150° to 200°C. and including xylol. Hiflash naphtha or heavy gasoline would come in this group. They usually comprise 4 to 10 per cent. of spraying lacquers, but would form a larger percentage of brushing lacquers. (4) Plasticizers boiling above 300°C. and not included in the foregoing list as they are non-volatile at ordinary temperatures and are used only in small amounts. Therefore they are not a potential menace to the sprayer as ordinarily used.

Methods Employed

In selecting the concentrations of the various substances for use in the gassing chambers, both their volatility and their percentage occurrence in lacquers were taken into account, higher concentrations of the low boilers being used than of any others, as a rule. In determining maximum concentrations the authors were guided by their experience in the field sampling of such vapors in the two surveys referred to and in a series of tests made in textile leather plants using benzol or toluol with ethyl acetate and alcohol as solvents. In an auto body factory with poor and almost negligible exhaust ventilation a maximum concentration of 6,500 parts per million of nitratable vapors reported as benzol was encountered, and several tests made in textile leather factories where a benzol "dope" was being flowed on gave over 10,000 parts per million of benzol vapor at the coater's station. It was felt that in tests of this kind it would be best to consider first the maximum possibilities of exposure where little or no exhaust ventilation was available. If these conditions showed toxic concentrations of the substances being tested, tests were to be made at concentrations likely to be obtained where reasonable and usual exhaust ventilation was provided but not necessarily of the degree of ventilation recommended for materials containing benzol or lead.

With the foregoing ideas in view, first tests were usually made based on a total mixed vapor concentration of 10,000 parts per million and a proportionate concentration of the substance being tested based on its usual percentage occurrence and its boiling range.

In the series of tests here reported, guinea-pigs used as test animals were, as a rule, kept under observation for at least two weeks before gassing was started. During this time, at least two blood counts and one urine examination were made. Animals were weighed at approximately weekly intervals and blood counts and urine examinations were made every two weeks. Blood counts were always made in the morning before feeding so as to avoid as far as possible digestive leukocytosis; in spite of this precaution, however, counts were quite variable even in control animals. Because of these normal variations,

little stress was placed on even wide differences between any two successive counts unless the differences were maintained in subsequent counts. Variations in feeding, it was noted, would cause more difference between successive counts than would any of the substances tested, and so only continued and increasing trends were considered significant. An illustration of procedures is given in Table 1 and in Figures 1 and 2.

During the first two weeks exposures were made every day; after that they were almost always for four-hour periods each day for six days a week. It was felt inadvisable to use longer exposure periods as there might be some confusing effect from malnutrition, since the animals will not eat in the gassing jars or for some time after removal therefrom. The exposures were continued for periods ranging from one month to two and a half months, unless individual animals succumbed to the effects of the vapor or to accidental infections. At least three animals were used for each solvent tested; where animals succumbed early in the gassing period, others were substituted for them. An endeavor was made to keep the animals in good condition by careful attention to diet and by meticulous care of the living quarters.

During the first series of exposures in the spring and summer of 1927 it was always possible to have fresh green food at every feeding, but there were several periods during the second series in the following fall and winter when for a few days at a time no green food was available.

Tests with Individual Solvents

Toluol

The material for these tests was specially purified before use by repeated careful distillation through a 25-ball Snyder column so that it would be free from benzol. The cut taken had a boiling range of less than 0.02°. Toluol, the most frequent substitute for benzol in industry, especially since the publication of the Benzol Report (2), was started at the high concentration of 4,000 parts per million, in spite of its position among the medium boilers, as it is often used in high concentration. This substance was tested on experimental animals as part of the National Safety Council benzol investigation but these gassing tests were twenty-hour exposures daily for seven days. This is too long a continuous exposure to be kept up for as many days as was planned in the study being reported here, as was stated above. In addition to the effects of malnutrition due to the long, continuous exposures, a seven-day period is too short to develop characteristic blood pictures, except in the case of extremely toxic substances such as benzol, and even here the partial starvation might add to the picture. Blood counts are so variable with the small experimental animals that except in these extreme conditions, as when the Benzol Report instances a white cell reduction up to 90 per cent., a considerable series of counts at intervals is necessary before one can be sure of negative or positive action. In normal controls considerable variations often occur and uniform findings

from time to time are the exception. In the United States Bureau of Mines studies on the tetraethyl lead hazard (7), successive counts of white cells in normal controls varied from 9,300 to 28,000 per cubic millimeter. One animal exposed to gasoline vapors showed almost a 50 per cent. drop in five days, only to regain more than half of this loss in the next eight days.

Toluol exposures were started at 4,000 parts per million but two of the three animals died after a few exposures, and the third was severely prostrated. A new series was started at 1,250 parts per million. This again seemed to affect the animals very much, although they survived eighteen exposures. The last series, at 1,000 parts per million, was continued for thirty-five days with no untoward happenings.

These tests showed that high concentrations of toluol are certainly dangerous for animals and there is no reason to suppose that they would not be dangerous for men. The animals exposed to 1,000 parts per million were not materially affected by the exposure. There were some evidences of early toxic degeneration in the liver and kidneys, but these were comparatively slight, and guinea-pigs in captivity are particularly susceptible to similar changes. The animals exposed to higher concentrations all showed much more marked degeneration in these organs and also marked pulmonary inflammation. With any reasonable amount of exhaust ventilation, 1,000 parts per million of toluol vapor would not be exceeded in lacquer spraying, as field tests did not show nitratable vapors much above this where even moderately good ventilation was found.

The Benzol Committee studies (2) started with 1,600 parts per million of toluol, which killed all animals exposed, in from forty-eight to seventy-two hours. With 1,250 parts per million they had no deaths in the seven-day period of their test, but four out of five animals tested showed evidences of narcosis and irritation or depression. With 1,100 parts per million, four animals were apparently not harmed in the seven-day period, but one out of four exposed to 620 parts per million showed some instability. Considering the differences in methods, these results agree fairly well with those reported here.

Xylol

The xylol used was redistilled from Eastman Kodak Company's meta-xylene, collecting material boiling through a 0.1° range. The first exposures to xylol were at a concentration of 450 parts per million, it being a higher boiler and not likely to occur in larger amounts in the fumes to which sprayers are exposed unless used in considerably higher percentages than is usually the case. At this concentration one animal died on the first day and the others seemed decidedly prostrated; the concentration was therefore reduced to 300 parts per million and continued for sixty-four exposures. With this concentration there was not much evidence of definite harm, although 450 parts per million seemed to affect the animals considerably and apparently killed one of them. Histologic examination of the organs of all of this group showed slight degeneration in the liver and evidence of inflammatory conditions

in the lungs, usually undergoing resolution.

In the fall these tests were repeated with other animals which received a concentration of 300 parts per million for fifty-eight exposures. There was little if any definite evidence of harm except for small areas of chronic catarrhal inflammation in the lungs of two of the group, and scattered, moderate tubular degeneration in the kidneys. These two series of tests show that even with a moderate degree of exhaust ventilation xylol should not produce any harmful effects, though, as with toluol, it should never be used without some exhaust ventilation.

Four rats exposed to 980 parts per million of xylol for seven days, in the Benzol Committee study, all showed marked effects. Eight rats exposed to 620 parts per million for seven days showed no ill effects. Quantitatively these tests do not check as well with those reported in this paper as do the toluol series but they show the harmfulness of high concentrations, which, however, are not likely to be met with in lacquers.

Gasoline

The gasoline tested in these studies was obtained directly from a supply tank in a lacquer factory. It had a boiling range near that of the Hiflash naphtha tested by the Benzol Committee and above that of gasoline tested by the United States Bureau of Mines laboratories in the tetraethyl lead gasoline studies (7). Ten per cent. distilled below 145°C. and 90 per cent. below 183°C.

Gasoline exposures were at a concentration of 1,500 parts per million, as it may be used in fairly high percentage in a brushing lacquer. All three animals tested showed fairly consistent gains in weight except during one hot period in June when they fell off moderately but again picked up. They had sixty-five exposures.

During the early exposures the animals seemed to feel the narcotic effects of the vapors decidedly, being at first restless and then rather heavy. They developed a diarrhea which, however, did not continue long. They also showed an early temporary albuminuria. At the end of the test period they seemed in good condition, although there was evidence of beginning toxic degeneration in the livers. There were no characteristic blood changes, and the lungs were clear. The early period of disturbance would seem to indicate that this was about the upper limit of concentration that could be used with safety.

The Benzol Committee studies, using a Hiflash naphtha, found 567 parts per million somewhat irritating to rats with a twenty-hour daily exposure for seven days, but found 312 parts per million harmless in the seven-day period.

Ethyl Acetate

This material was collected through a boiling range of 0.02° from a sample especially prepared for a previous investigation.

Ethyl acetate, a low boiler, was used at a concentration of 2,000 parts per million. Three animals tested all continued in good condition and showed no definite evidence of harm for a period of sixty-five exposures. Evidently this concentration is a safe one for use and with exhaust ventilation it might be considerably exceeded.

Butyl Acetate

Butyl acetate was once distilled from Eastman Kodak Company's *n*-butyl acetate collecting the portion boiling through a 0.1° range. In the Pennsylvania studies (1) butyl acetate was tested at 500 parts per million for thirty-six three-hour exposure periods, and at 1,000 parts per million for ten two-hour to three-hour periods, but without reaching any definite conclusions. The first series seemed to show some harmful effects as evidenced by depression during the early gassing periods and by some renal changes, but these were not confirmed by the longer exposures to 900 parts per million in the present investigation which were continued over sixty-five exposure periods; therefore the renal changes may have been due to some other cause.

Concentrations of 900 to 1,000 parts per million would seem to be reasonably safe for this substance, and so with exhaust ventilation of reasonable efficiency the concentration might even be increased above the amount used at present, according to information received from lacquer makers.

Amyl Acetate

Chemically pure amyl acetate as purchased was used. In the Pennsylvania studies amyl acetate was used for the same period and the same time exposures and concentrations as was butyl acetate, but with no evidence of harm during gassings or on autopsy. As these tests were entirely negative as far as harmful effect was concerned, they were not repeated in this study and amyl acetate was considered as among the safest of the solvents studied, in the concentrations used.

Ethyl Alcohol, Formula 2b

This is the denaturing formula provided for this type of industrial use. It was employed at a concentration of 3,000 parts per million for sixty-four exposures. In spite of the small amount of benzol present in this material, 0.5 per cent., no deleterious effects were observed, except for slight transient albuminuria in one animal. Evidently this concentration of this type of industrial alcohol can be used with safety in lacquers.

Butyl Alcohol

Butyl alcohol prepared in a similar manner to the butyl acetate was used at 100 parts per million and the animals survived the entire sixty-four exposures. In spite of the very low concentration at which this was used, based on information obtained from lacquer makers, the animals showed a definite change in the blood picture. There was a decrease in the red cell counts and a relative and absolute lymphocytosis, this being the only group of animals to show a definite and constant shift in the differential counts. Two of the three animals first tested showed hemorrhagic areas in the lungs and also a transient albuminuria.

Owing to these findings with such a low concentration, a second series of animals was exposed to the same concentration in the fall. After more than thirty exposures they all developed a very severe skin infection, which prostrated them so that two died in the gassing chamber during the thirty-eighth exposure. These animals also showed a decrease in red cells and in hemoglobin and an

increase in leukocytes. Owing to the infection, however, the polymorphonuclears predominated toward the end of this period. The survivor gained in weight and had a decidedly improved blood picture at the time of killing. The livers of these animals showed early toxic degeneration and there was considerable evidence of renal degeneration, both accentuated probably by the infection.

After the death of the two animals from this group, a third series was started at the same concentration and was continued for twenty-eight exposures. These animals also showed early liver degeneration with more marked renal degeneration. A definite decrease in red blood cells, with an absolute and relative lymphocytosis, confirmed the findings of the first series. These tests taken together indicate that butyl alcohol should be used with caution and in only small amounts in lacquers.

The records of the tests in the third group of butyl alcohol exposures are given in Table 1 and Figures 1 and 2, as an illustration of procedures. In this group, two of the animals had to be used without preliminary testing of the blood and urine but this was the exception and not the usual practice.

Steam Distilled Turpentine

This type of turpentine was selected as it was that in use in a lacquer manufacturing plant from which samples of other materials had been secured, but the results obtained check very well with those obtained with gum spirits turpentine tested by another worker whose report to a lacquer firm the authors have seen, but which has not been published so far as is known by them.

Steam distilled turpentine was used at 715 parts per million. Four animals were exposed to this solvent as one died after twelve exposures, probably as the result of some unrecognized infection. This animal was replaced with another which received forty-five exposures, the other two receiving fifty-eight. These animals made excellent gains in weight and showed no significant blood changes. Tissue examinations showed very slight changes in the livers with moderate scattered tubular degeneration in the kidneys. This concentration of steam distilled turpentine appears to be reasonably safe.

Spraying Lacquer Distillate

Distillate obtained from a widely used spraying lacquer purchased in the open market was tested in the same way as were the pure solvents. It was used first at a concentration based on a total volume of spray equivalent to 10,000 parts per million and on the percentage yield of volatile solvent vapors from the distillation; this gave a concentration of 6,100 parts per million. After twenty-five exposures the three animals became severely prostrated during each gassing period. One died during the thirty-second and another during the thirty-third exposure. Exposures were stopped with the third animal but it died eleven days later, having developed the severe skin infection previously referred to in discussing another group. As a rule, animals dying of this condition were not autopsied, as it was felt that no true readings of pathology could be had which could be

TABLE 1.—RECORDS OF THIRD SERIES OF INHALATION EXPERIMENTS WITH BUTYL ALCOHOL (100 PARTS PER MILLION OF AIR)

DATE[1]	WEIGHT IN GRAMS	BLOOD FINDINGS								URINE[3]	REMARKS
		Hemoglobin %	Red Cells in Millions[2]	White Cells in Thousands[2]	Polymorphonuclears %	Lymphocytes %	Large Mononuclears %	Eosinophils %	Basophils %	Specific Gravity	
Animal No. 38: Male											
11/9	275	76	5.5	10.9	42	54	3	1	0	.....	.....
11/15	268	..	...	....	..	..	..	..	..	.....	.....
11/21	317	83	5.8	5.0	37	58	4	1	0	.....	.....
11/26	...	..	...	....	..	..	..	..	..	1.017	.....
11/30	338	68	5.4	7.7	59	39	2	0	0	1.012	.....
11/30	Started in gassing chamber, 4 hours daily, except as noted.									.....	.....
12/4	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/5	404	..	...	....	..	..	..	..	..	.....	.....
12/7	...	..	...	....	..	..	..	..	..	1.011	.....
12/11	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/13	...	77	5.5	9.7	46	48	3	3	0	.....	.....
12/14	425	..	...	....	..	..	..	..	..	.....	.....
12/18	...	..	...	....	..	..	..	..	..		No gassing.
12/20	427	..	...	....	..	..	..	..	..	1.018	.....
12/25	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/30	528	73	5.2	8.7	36	62	2	0	0	.....	.....
12/31	...	..	...	....	..	..	..	..	..	1.010	.....
1/1	509	Purposely killed, 28 exposures, 112 hours.								.....	.....

Autopsy.—Apparently normal.

Pathology.[4]—*Liver:* Beginning central degeneration, not marked. *Kidney:* Cloudy swelling of convoluted tubes, marked degeneration of cortex and loop tubes.

Animal No. 39: Male											
11/30	244	88	6.5	5.1	35	56	7	1	1	1.017	.....
11/30	Started in gassing chamber, 4 hours daily, except as noted.									.....	.....
12/4	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/6	282	..	...	....	..	..	..	..	..	.....	.....
12/7	...	..	...	....	..	..	..	..	..	1.010	.....
12/11	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/13	...	76	5.2	6.0	21	73	3	1	2	.....	.....
12/14	308	..	...	....	..	..	..	..	..	.....	.....
12/18	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/20	338	..	...	....	..	..	..	..	..	1.030	.....
12/25	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/30	391	69	4.7	8.8	22	72	3	3	0	.....	.....
12/31	...	..	...	....	..	..	..	..	..	1.011	.....
1/1	383	Purposely killed, 28 exposures, 112 hours.								.....	.....

Autopsy.—Organs apparently normal.

Pathology.[4]—*Liver:* Beginning central degeneration, not marked. *Kidney:* Widespread degeneration of all types of tubules.

TABLE 1.—*Continued*

DATE[1]	WEIGHT IN GRAMS	BLOOD FINDINGS								URINE[3]	REMARKS
		Hemoglobin %	Red Cells in Millions[2]	White Cells in Thousands[2]	Polymorpho-nuclears %	Lymphocytes %	Large Mono-nuclears %	Eosinophils %	Basophils %	Specific Gravity	
Animal No. 40: Male											
11/30	310	87	6.4	8.3	39	57	4	0	0	1.020	.....
11/30	Started in gassing chamber, 4 hours daily, except as noted.									.....	.....
12/4	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/6	352	..	...	....	..	..	..	..	..	.....	.....
12/7	...	..	...	....	..	..	..	..	..	1.012	.....
12/11	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/13	...	74	5.2	11.9	39	58	3	0	0	.....	.....
12/14	376	..	...	....	..	..	..	..	..	.....	.....
12/18	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/20	397	..	...	....	..	..	..	..	..	.....	.....
12/25	...	..	...	....	..	..	..	..	..	.....	No gassing.
12/30	455	78	5.4	10.2	36	60	4	0	0	.....	.....
12/31	...	..	...	....	..	..	..	..	..	1.010	.....
1/1	445	Purposely killed after 28 exposures, 112 hours.								.....	.....

Autopsy.—Organs apparently normal.

Pathology.[4]—*Liver:* Beginning central degeneration. *Kidney:* Widespread degeneration of all types of tubules.

[1] Dates are entered only where observations were made. Where no date is given, the animal was gassed if that day was during the gassing period.

[2] Red blood counts are recorded to tenths of millions only; white blood counts, to tenths of thousands only.

[3] Albumin, sugar, casts, etc., were all negative.

[4] Organs not mentioned were normal.

definitely attributed to the solvent. The two animals dying in the gassing chamber showed marked evidence of lung irritation and inflammation and quite marked toxic degeneration in both liver and kidneys. Their weight gains during exposure had been only moderate and less than that of animals exposed to the pure solvents.

A second group was exposed to one-half the concentration of the first series, 3,050 parts per million. One of these animals died of the skin infection after seven exposures but the others survived twenty-two and thirty exposures respectively, making fair gains in weight and showing no definite deleterious effects in any way.

It is felt that this second concentration might often be exceeded in commercial spraying practice where there was poor or no exhaust ventilation, but with moderately efficient exhaust it would rarely be exceeded, and these tests indicate that it is probably not harmful.

Brushing Distillate

In like manner a widely used brand of brushing lacquer was distilled and

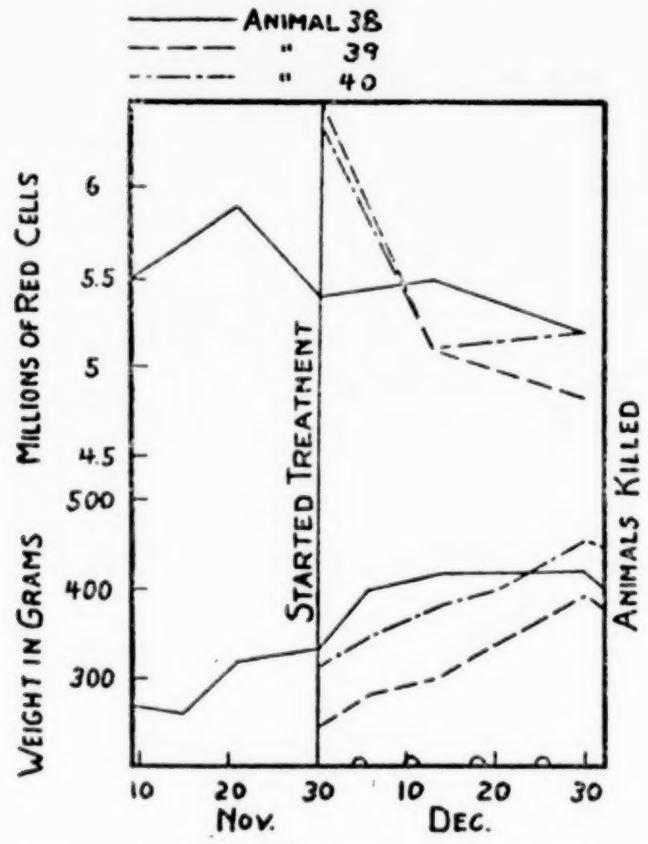

FIG. 1.—Weights and red blood cell counts for third series of butyl alcohol experiments.

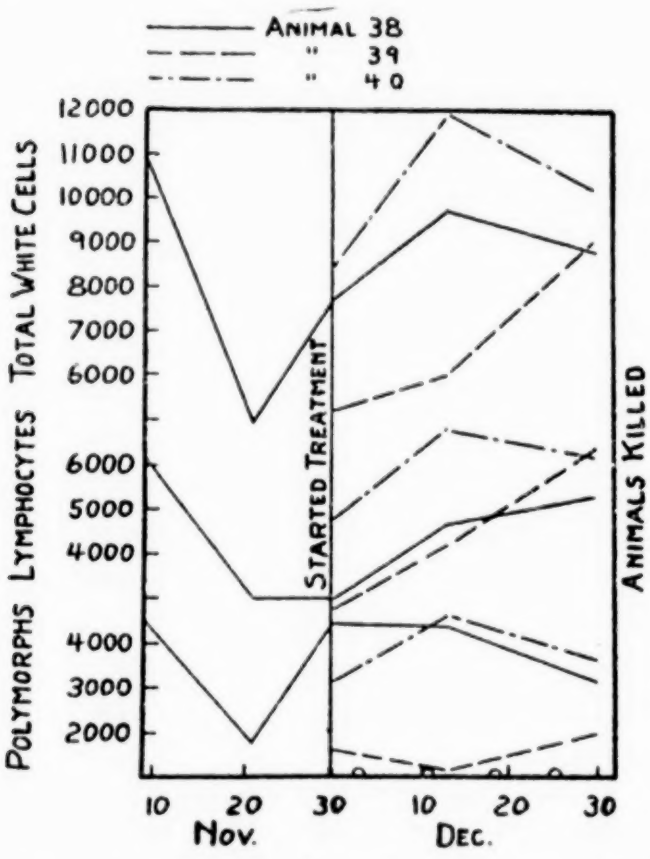

FIG. 2.—White blood cell counts for third series of butyl alcohol experiments.

the distillate tested. As this material is never sprayed, the degree of fume exposure during its use would be considerably less than with spraying lacquer. For these tests the maximum concentration was taken as 5,000 parts per million of liquid or 2,050 parts per million of the distillate.

Three animals were exposed to this concentration. One female died one day after delivery, after fifty-two exposures. She was found to have an infectious pneumonia. The other two animals had fifty-eight exposures. All three animals showed normal weight gains. The two males showed more or less generally distributed early degenerations in the liver and kidneys, not marked. As previously stated, these mild degenerative changes have little significance in guinea-pigs kept in close confinement.

It is felt that the concentration of brushing lacquer tested would be met with only where large surfaces were being covered in nonventilated quarters, and this practice is unusual and never a continuing one with brushing lacquers. In ordinary household use of brushing lacquers this concentration would never be approached.

Controls

Three control animals were placed daily, for the same periods as the animals being tested, in a gassing chamber to which only air was admitted. In addition to these, three others were kept with the colony, receiving the same food and attention, but not being exposed to any unusual conditions. One animal of each group died of the skin infection, but aside from this they were all completely normal and their organs showed no changes but the slight ones often seen in laboratory animals. In the tests, degenerations were not considered as

significant unless they were marked or widespread.

Discussion and Summary

As the result of the series of tests here reported the authors would divide the solvents tested into three groups:

1. Those usable with safety in concentrations usually employed or possibly in somewhat higher concentrations as ingredients of brushing or spraying lacquers. Ethyl acetate and amyl acetate, and possibly butyl acetate, would be placed in this class.

2. Those usable with safety in present concentrations but to be increased with caution as possibly harmful if increased materially. Here would be listed gasoline, turpentine, and xylol.

3. Those for which the present practice probably represents nearly the upper limit of safety in use as spraying lacquer constituents. In this group are toluol and butyl alcohol.

Provided reasonable exhaust ventilation is assured, however, all these limits may be appreciably raised with impunity.

The entire investigation furnishes a strong argument for the insistence on exhaust ventilation wherever lacquers of any type are being sprayed.

The materials listed and tested here do not nearly exhaust the list of those used as lacquer materials and the fact that practice in this respect is still frequently changing and new ingredients continually being introduced, about which there is available no information as to their effect on the health, is another argument for the protection of the sprayer in all cases. The removal of benzol from lacquers will undoubtedly remove the greatest single hazard from either acute or chronic poisoning in lacquer work but it does not warrant the discarding of precautionary measures.

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THE METHOD OF ACTION OF SILICA DUST IN THE LUNGS*

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UP to the present time, two different explanations have been offered, one physical and the other chemical, to account for the action of silica dust in the lungs.

The oldest explanation is that the silica dust, by virtue of the hardness, sharpness, and insolubility of its particles, produces innumerable minute wounds throughout the lung substance, and that the resultant little nodules of scar tissue constitute the typical silica fibrosis. In support of this theory, it was pointed out that particles of silica can be recovered from the fibrosed parts of the lungs after death.

It soon became obvious that this theory was inadequate. It was shown by animal experiments that, in order to enter the lung tissue, the dust particles had to reach the pulmonary alveoli, whence they are taken into the lungs by the macrophages, and that no particles exceeding 10 microns in greatest diameter enter the pulmonary tissue (1) (2) (3) (4). On the other hand, there is no minimum limit to the possible fineness of the offending dust. Much of it is probably ultramicroscopic. The limit of resolving power for an ordinary microscope is about 0.15 micron. We know that ultramicroscopic dust is capable of floating for long periods in suspension in the higher layers of the earth's atmosphere, producing many of the color effects seen in the skies at certain periods. Some consider this dust as a suspensoid in brownian movement.

In dealing with dust particles of these dimensions, we are in a region where the molecule is a reality (the diameter of a molecule of hydrogen is said to be 0.00016 micron), and where surface tension, surface energy, and electric charge are of greater importance than hardness, sharpness, or weight. Direct mechanical injury to the lung is, as Gye and Kettle say, in the circumstances under which dust gains access, "almost inconceivable." Furthermore, silica is by no means the insoluble substance that the older school believed, since, while resistant to the action of strong acids, except hydrofluoric, it is fairly readily soluble in alkalies, forming, however, colloid sols, not ionized solutions. The fineness of these emulsoids may be so great, in certain circumstances, that they show no Tyndall effect (5). Kettle (6) has shown that fibrosis results when the tissues of the body are subjected to the influence of this colloidal silica

* From an address on "Silicosis," delivered to the North Western Tuberculosis Society at Manchester, March 29, 1928. Received for publication March 26, 1928.

sol. Finally, scar tissue, mechanically produced, should not favor subsequent tuberculosis.

It is obvious, therefore, that the "direct injury" theory is inadequate to explain silicotic fibrosis and silicotic tuberculosis.

The second explanation offered is the chemical theory of Gye, Purdy, and Kettle. According to these observers, the silica ion[1] is toxic to mice, guinea-pigs, and rabbits (8, III, p. 250). Silica, they say, is a cell poison, and colloidal silica sol, when injected intravenously, parenterally, or subcutaneously into these animals, produces highly characteristic reactions which they appear to attribute to the "toxicity" of the silica ion (6) (7) (8).

For example, after injection of silica sol into the subcutaneous tissue of a mouse, "There occurs a central mass of necrosis surrounded by a zone of leukocytes; outside this is a zone of spreading secondary necrosis, which is bounded by an area of organizing inflammatory fibrosis. In the course of time the necrotic tissue becomes absorbed and replaced by the invading fibrous tissue, and late lesions are represented by nothing more than a fibrous scar . . . . there can be no reasonable doubt that it [the silica] brings about its results by its chemical action on the tissues and cells." After detailing some experiments with "collodion sacs, having an appropriate degree of permeability," Kettle writes, "Insoluble silica . . . . becomes hydrolyzed in the tissues and, *as a soluble protoplasmic poison*,[2] is able to exert its action on the cells" (6).

Kettle then goes on to describe how tubercle bacilli, injected with silica into the subcutaneous tissues of mice, proliferated to an enormously greater extent in the coagulum of the silica lesion than in control mice into which tubercle bacilli were injected without silica. He offers several suggestions to explain this phenomenon, realizing its importance and its bearing on silicotic tuberculosis. As will be seen later, Professor Lyle Cummins (9) has shown experimentally that the explanation lies in the region of colloidal physics, and is due to the adsorption of complement by the colloidal silica.

The painstaking and thorough experimental work of Gye, Purdy, and Kettle has gone a long way toward clearing up the question of the action of silica in the tissues, and inferentially in the lungs. Thanks to these investigators, it is known that colloidal silica has a definite action when introduced into animal tissues, and Kettle has shown that insoluble silica oxide suspended in distilled water, and enclosed in collodion sacs having an appropriate degree of permeability, produces, in time, much the same effect as ready-made hydrated silica sol. First, a coagulum is formed (in which the tubercle bacillus multiplies if introduced therein) and, eventually, a fibrotic nodule (6).

But where some—including the authors—cannot quite follow Gye, Purdy, and Kettle, is in the purely chemical explanation which they offer for their observed phenomena. All through their published papers, the terms soluble protoplasmic poison and cell poison recur. Gye and Kettle write: "It has been shown that colloidal silica is a toxic substance" (7, p. 243). We feel that this description

[1] Gye and Purdy write "the silicon ion."
[2] The italics are mine.—P. H.

of colloidal silica needs some qualification.

If silica is a soluble protoplasmic poison, how is it that there is "an enormously greater proliferation of the tubercle bacillus" (to use Kettle's own words) in a silica coagulum in the tissues than in the same tissues in the absence of silica? "The action of chemicals on bacteria can be regarded as a simple chemical reaction, the germicide being one reagent, the bacteria the other" (10). "Santon has shown that a small piece of silver, introduced into a culture of tubercle bacilli, stops altogether the development of the culture, although no silver can be detected in the liquor. Nageli has demonstrated that algae would live in pure distilled water, if the water had been distilled in a glass (soda-lime silicate) apparatus, but would die if the water had been in touch with any copper container, pipe or tap, although no trace of copper can be found in the water" (10).

But the addition of silica to water has no such lethal or inhibitory effect, even when the amount is quite considerable. All spring and well waters contain silica. Buxton water contains 0.95 grains of "silicic acid" to the gallon. The mineral waters of Bath and Matlock contain 1.96 and 0.71 grains of silica to the gallon (11). Beer contains from 288 to 840 mg. of silica per liter (8). Practically all vegetable foods contain some silica; some contain a great deal of it. The connective tissue of every one of us, of every plant, every adult animal, including probably the rabbits and mice with which Gye and Purdy experimented, contains silica. Normal urine contains silica to the extent of 30 mg. per liter (8). The framework of some members of the animal kingdom, *e.g.*, sponges, is mainly composed of silica. Every molecule of that silica has gone through the metabolism of these creatures.

There is another interpretation, which is, we believe, sufficient to explain the action of colloidal silica on the blood cells and serum, endothelial cells, liver cells, lung parenchyma, and other tissues; moreover, it offers an explanation of certain hitherto unexplained clinical phenomena in connection with silicosis—*viz.*, the protecting influence which certain substances such as coal dust, shale dust, graphite, argillaceous and kaolinitic material offer against the action of silica dust. It is that the action of colloidal silica sol on animal tissues is essentially an adsorptive and coagulant one. That is to say, silica sol acts on animal tissues, not as a soluble protoplasmic poison, but simply as an active colloid, adsorbing, possibly selectively, fluids such as complement, serum, and cell protoplasm; coagulating colloids of opposite sign; agglutinating or laking blood corpuscles according to the concentration or massiveness of the dose of colloid; and, in fact, producing all the phenomena described by Gye and Purdy, not because it is poisonous, but because it is a colloid of great surface energy.

It is now generally admitted that many biologic interactions formerly regarded as specific are really non-specific, and are of the nature of inter-colloidal physical phenomena. There is, we believe, evidence to show that the action of silica sol on living tissue is one of these.

Colloidal silica is one of the most

powerful adsorbents we know (12, p. 295ff.). Furthermore, its adsorbent action is selective. "Alkalis are strongly adsorbed, and solutions of salts of the feeble acids are decomposed, and part of their alkaline base is selectively absorbed by the silica, e.g. alkaline carbonates, phosphates, borates and calcium carbonate. Adsorption thus appears as a kind of incipient combination." Again, "T. Graham prepared sols and gels of silica with fluids other than water, e.g. . . . . formic, acetic and tartaric acids, sugar group, glycerol, benzene, carbon disulphide, alcohol, ether and fixed oils. These liquids can displace more or less water without gelatinising the dissolved silica." Again, Kolmer (13) writes, "Inorganic colloidal solutions, such as that of silicic acid, may produce hemolysis of red blood-corpuscles, *e.g.*, those of the rabbit. Its action is manifested in extremely small doses. . . . . An excess of silicic acid tends to prevent hemolysis, which is another example of the action of an excess of one colloidal solution upon another of opposite sign."

We now come to the studies of Professor Lyle Cummins on the action of colloidal silica sol upon blood (9) (14).

In 1913, Mutermilch and Bankowski had shown that both colloidal silica and colloidal alumina had the property of adsorbing complement, although, normally, silica sol and alumina sol are of opposite sign. Cummins, working with typhoid cultures, showed that the addition of silica sol inhibited, in a most marked degree, the action of the bactericidal substances of the blood, allowing the bacteria to develop freely *in vitro*, as the tubercle bacillus did *in vivo* in Kettle's fixation abscess experiment. Furthermore, a sodium chloride-silica colloid sol prevented the hemolysis of sensitized red blood corpuscles by complement, presumably by adsorbing the latter, and a similar sol was found to cause immediate and gross clumping of washed red blood corpuscles, in the absence of serum. But the addition of strong serum prevented this, and, according to Cummins, this "inhibition seems to depend upon the formation of a gel."

From the foregoing, it will, we think, be admitted that the results obtained by Gye, Purdy, and Kettle, Professor Lyle Cummins, Mavrogordato, Fenn, and Carleton, and the clinical and statistical studies, by many observers, of the production of disease by silica, when interpreted as the results of the action of a soluble inorganic protoplasmic poison, are confusing and contradictory. When interpreted, however, as examples of the interaction between a powerful inorganic colloid and organic substances, themselves colloidal in nature and of varying dispersion and sign, the observed phenomena appear more capable of correlation. Gye and Purdy tell us that "the potency of a solution is very profoundly affected by the degree of dispersion—even . . . . in the production of chronic changes." Their minimal dose, capable of producing toxic symptoms was, for a rabbit, 5 mg. of silica, but they say "This applies only to freshly prepared highly dispersed sol; in older preparations of silica sol in which aggregation has occurred much larger doses may be given without producing lesions." The change from the silica sol to the silica gel condition was retarded by traces of acid or alkali, or by a pro-

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tective colloid, *e.g.*, albumin. The cells affected were, with large doses, the blood corpuscles; with smaller doses over prolonged period, the endothelial cells, that is to say, the cells with which the colloid sol came into physical surface contact.

The observation of ghosts of endothelial cells, which had "become greatly swollen and vacuolated and then died," the infarctions which were found, probably due to emboli of corpuscles agglutinated by the foreign colloid, the frothy protoplasm of the enlarged endothelial cells, the absence of fibroblasts, the dilated hepatic sinusoids becoming surrounded by thickened fibrosis, the intravenous clotting of the blood of the rabbits who died fulminating deaths after receiving, intravenously, large doses (150 mg.) of freshly prepared silica sol, all point to a colloidal interaction rather than to a chemical poisoning.

When we turn to the feeding experiments, Gye and Purdy tell us that "In rats, mice, guinea-pigs and monkeys there were no pathological changes produced by feeding with silica." These authors also state that "The absence of lesions in the liver leads us to suppose that the silica is not absorbed from the gut, or alternatively, that if it is absorbed it is in some way rendered innocuous."

At this stage we would suggest an alternative theory to explain the phenomena which occur in the lungs in the course of pulmonary silicosis and silicotic tuberculosis. The fragments of quartz, many no doubt ultramicroscopic in size, having come to rest in the lymph spaces of the pulmonary tissue, are gradually hydrated into colloidal silica (7). The latter exerts its adsorbent powers on the protoplasm of the macrophages containing the silica, adsorbing the fluid, and increasing in bulk. Its activities spread to neighboring cells, which are in turn similarly influenced, leaving the cell ghosts surrounding the central mass of silica sol plus protoplasmic fluid. This central colliquative mass is the "rich pabulum" in which, according to Kettle, the tubercle bacilli proliferate and grow luxuriantly. The ghosts and cell stroma form the whorled fibrotic wall surrounding the central mass, the whole constituting the pseudotubercle photographed by Professor Beattie (15), which we would regard as the basal unit of silicotic fibrosis, as the giant cell system is of tuberculosis.

With the conversion of the microscopic fragment of silica through a series of transitions to an eventual gel, the activity subsides, leaving the fibrous nodule, except where the tubercle bacillus has found a foothold, in which case the phenomena of a virulent tuberculosis—virulent because of the favorable conditions and the rich pabulum provided by the colloidal silica-protoplasm mixture—is added to that of silicosis. Furthermore, this hypothesis correlates certain clinical and experimental observations as to the protection afforded by coal dust, shale, and kaolinitic material against the production of silicosis in men and animals by silica dust.

Clay substance, *l'argile véritable*, is, in the presence of water, one of the most active colloids. As fuller's earth, it selectively adsorbs fats, unsaturated hydrocarbons, and sulphur compounds; as osmo-kaolin it adsorbs the toxins of cholera and other bacteria in the

bowel. Chemically a hydrous aluminium silicate, it is normally of opposite sign to colloidal silica, and the two mutually coagulate one another when brought into contact (12, p. 296). Here we have an explanation of the formation, in nature, of the "pellicle of kaolinitic material surrounding the particles of quartz, in Derbyshire pocket silica sand."[3]

In the presence of this protective coating of coagulated aluminium silicate, it is suggested that the silica particle remains inert and harmless, unable to assume the active colloid condition. And hence would arise the protection afforded by kaolinitic and clayey material against the action of silica dust in the lungs of the silica brickmakers, noted by Smith and Collis in Yorkshire (16), and by one of us in Derbyshire (17).

With regard to carbon, we know that silica sol is coagulated by graphite (12, p. 296). Mavrogordato and Carleton have shown that coal dust protects guinea-pigs against the effect of subsequent exposure to silica dust, so that the chain of evidence is nearly complete (1) (2) (4).

Some observations by Dr. Tattersall (18) among hard ground workers in certain South Wales coal mines are considered by some to contradict the experimental work of Mavrogordato and Carleton, but we do not know that these workers were previously subjected to the action of coal dust, and we do know that the latter is rapidly eliminated from the lungs (2).

While searching for further information regarding the action of carbon, coal dust, etc., upon silica sol we noticed that, according to Mellor (12) and Taylor (5), stannic acid sol closely resembles silicic acid sol in its general behavior. This statement starts a train of speculation. We know from the Registrar-General's occupational mortality figures that the death rate from tuberculosis among tin miners is remarkably high; higher than one would expect from the silica content of the ore and stone in which they work. May the action of colloidal stannic acid supplement or augment the action of silicic acid in the lungs of these workers? And having started our train of speculation, we cannot stop there. Other materials, active in the colloidal state, are under suspicion. If colloidal silica can selectively adsorb complement and so inhibit the bactericidal power of the blood, as shown by Professor Cummins, may not other colloids of similar sign, etc., do likewise? In effect, can other phenomena bearing on immunity, susceptibility, and resistance to disease be explained on the basis of colloidal physics?

Summary

1. Silica is an ordinary constituent of animal and vegetable tissues, and is found in the urine.

2. The evidence adduced to show that the silica ion is toxic to animals is not convincing. The evidence *contra* is strong.

3. Silica in stable combination and crystalline silica appear to be harmless while in those states.

4. Colloidal silica is harmful to certain animal tissues when brought into surface contact with them. When administered intravenously in sufficiently large doses and in an active

[3] Report of Geological Survey, 1920, *6*, 168.

colloid condition, it may cause immediate death.

5. The harmful effects of colloidal silica appear to be due to its powerful potentialities as a colloid, rather than to any toxicity of the silica ion.

6. Pulmonary silicosis is probably caused by the colloidal action of hydrated silica, formed from minute particles of silica dust disseminated through the pulmonary tissue.

7. There is evidence to show that the activity of colloidal silica in the lungs may be prevented by protecting the silica dust with a coating of a substance which is known to coagulate colloidal silica. Such substances are clay substance, carbon, shale dust, etc.

8. Possibly other colloids, *e.g.*, stannic acid sol, may be capable of acting in the tissues in a similar manner to hydrated silica.

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THE GRAVIMETRIC DETERMINATION OF DUST INHALED BY WORKMEN*

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THE dust hazard, as is well known, occupies a place of increasing importance among occupational health hazards.

In studying this problem from the point of view of industrial hygiene, it is essential to know the amount of dust inhaled by workmen over a definite period of time in industries which liberate the various kinds of poisonous dusts.

The method generally used to determine the quantity of dust inhaled in a given place consists in drawing air through a filter[1] and determining the amount of dust retained, the result being computed in terms of a unit volume of air. The amount of dust which a man inhales in a given period is then calculated on the basis of the assumption that the amount of air breathed by a man in one hour averages from 400 to 500 liters (1) (2).

Various authors adopt various methods for the gravimetric determination of dust; the methods differ with regard to the size of the intake of the filter, the direction of the intake, the velocity of the air aspirated, the character of the aspiration itself—whether instantaneous or continuous throughout sampling—and, finally, with regard to the nature of the filter.

The gravimetric method of determining the amount of dust inhaled by man contains, without doubt, two serious inaccuracies. In the first place, it is erroneous to assume that the dust content of the air can be estimated by drawing the air through a filtering medium and determining gravimetrically the dust retained on the filter; in the second place, the amount of dust shown by the gravimetric determination thus obtained cannot be compared with the amount of dust inhaled by man, because the operation of the usual dust sampling instruments does not in any sense imitate the functioning of the respiratory apparatus of man.

A more correct way of determining the weight of dust in a certain volume of air is to isolate the volume of air, taken during a definite period of time in the desired place, to precipitate, collect, and weigh the dust it contains, expressing the result in terms of a unit volume of air. This method, however, is impractical for obvious reasons. In practice, the amount of dust in air is

* This article, in its main features, was published in Russian in 1926 (*Gigiena Truda*, 1926, no. 1, pp. 27–45). Received for publication March 10, 1928.

[1] If an electric precipitator is used, there is no need of a special filter.

determined, as has already been said, by drawing air through some filtering or dust catching medium; but, by drawing air, we create a current in the direction of the aspirating instrument and so carry away the particles of dust which fall in with the moving stream.

Whether or not a dust particle falls in with a moving stream depends on several factors: (*a*) the negative pressure at the intake of the filter; (*b*) various atmospheric conditions, such as air motion, humidity, and electric state of the air; and finally (*c*) a whole series of physical properties of the dust particles themselves, such as dispersion, specific gravity, size, and shape. Of these factors, one of the most important is the negative pressure at the intake of the filter.

Thus in determining the amount of dust in a certain room, we can collect on the filter varying amounts of dust particles, depending on the manner of sampling. We may conclude, therefore, that the gravimetric determination of dust by means of drawing air through a filter represents only the amount of dust which is in the air passing through the filter, but by no means the amount of dust in the air of the room itself. Such investigations, therefore, must be considered purely experimental, giving, under the best conditions, comparative figures for the dustiness of a certain room if precisely the same methods are employed in each investigation.

Is it possible, then, to draw conclusions from data secured in this manner as to the amount of dust inhaled by man? It is evident that such conclusions will be accurate only if the aspirating instrument used imitates exactly the operation of the respiratory apparatus of man. Since the instruments which have been used in the gravimetric determination of dust in air have not conformed to this condition, it is reasonable to assume that serious errors have hitherto resulted.

Let us compare the essential features of the human respiratory apparatus with those of the instruments used in dust determination. The cross-sectional area of the aspirating opening of the filter, as Recknagel pointed out, must average 1.5 sq. cm. in order to be comparable to the cross section of both nostrils of man.[2] The cross-sectional area undoubtedly influences the amount of dust drawn in, because the negative pressure at the intake of the filter varies inversely with this cross-sectional area. Moreover, the filter intake is usually directed horizontally; sometimes its direction is vertical and upward (*e.g.*, in the case of the sugar tube and the thimble); but it does not point vertically downward like the nostrils of man. This difference, again, must influence the amount of dust drawn into the dust sampler.

Let us take, for example, two tubes containing filters (see Fig. 1), tube A with the intake directed downward and tube A' with the intake directed forward. Let m represent a dust particle at the filter of tube A, and m' such a particle at the filter of tube A'. For simplicity we shall assume that each particle is under the influence of only two forces, gravity and suction. Let mn represent the force of gravity acting on the first dust particle and mp the suctional force tending to draw

[2] I have in mind the normal nose breathing of man, not mouth or mixed breathing.

this particle into tube A. Let $m'n'$ and $m'p'$ be the same components acting on the dust particle m' at the entrance of tube A'. It is evident that particle m will be drawn into A only when the suctional force is stronger than that of gravity; *i.e.*, mp must be greater than mn. Particle m', with a gravity component $m'n'$ and a suctional component $m'p'$ acting at right angles to each other, will follow the direction of the resultant or diagonal of the rectangle. The particle m', therefore, may enter A' when $m'p'$ equals $m'n'$ and even when $m'p'$ is less than $m'n'$.

When the intake of a filter is directed upward (as in the sugar tube and thimble), the effect of gravity on particles falling into the filter is still greater; it is then possible for particles to fall in, even when they are very small and when the suctional force of the instrument is likewise small or even nonexistent.

Hence it is evident that the position of the intake of the filter may have considerable influence on the results of the gravimetric determination of dust. With an instrument of small suctional force and with dust particles which differ widely in size and dispersion, results will vary markedly.

Tests which I have made with sawdust and cement dust show conclusively that the direction of the aspirating intake of the filter has undoubted influence on the amount of dust drawn into the filter. The dust clouds were put up by a duster, specially designed, and samples were taken by the same instrument (bottle system) into two filters identically the same. The only difference in the procedure was that the intake of one filter was directed downward and that of the other, upward.[3] The weight of the dust collected by the filter with the intake

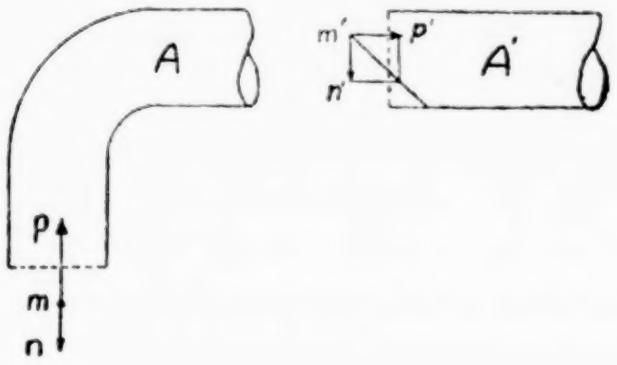

FIG. 1.—Diagram showing effect of suction (p) and gravity (n) on course of dust particle (m) at entrance to tube (A) containing filter.

pointed upward was greater than the weight of the dust retained by the filter which had its intake pointing downward. Moreover, the average size of the particles retained in the first filter was greater than the average size of those retained in the second filter.

In view of these observations, therefore, if we wish to interpret gravimetric determinations in terms of the amount of dust inhaled by man, it is necessary that the intake of the filter imitate the openings of the human nose both in regard to size (Recknagel) and in regard to position, that is, the opening should be directed downward.

Turning to the question of the functioning of the different instruments used for dust sampling, it should be noted that they differ both in the amount of air which they draw in in unit time and in the method by which this is accomplished, some instruments producing continuous and others intermittent suctional force. Since the negative pressure developed at the intake of the filter depends on the size

[3] The interior surface of the downward portion of the first filter was greased before the test, in order to retain those dust particles which touched there.

of the intake and on the suctional force applied, and since these two conditions differ in the various instruments used, the amount of dust caught likewise varies.

This statement is supported by a series of experiments carried out in 1926, in which dust was sampled simultaneously by five different instruments: the Petri pump, bellows, water spray pump, a bottle system, and a double aspirator. The filters were placed at the same height, close to each other, and had intakes exactly alike pointed horizontally forward in the same direction.

The negative pressure at the intake of the filters, as shown by preliminary tests, varied as follows:

	mm. water column
Petri pump	30–70
Bellows	15–70
Water spray pump	2–3
Bottle system	about 2
Double aspirator	about 1

With the first two instruments, the negative pressure varied according to the speed of the pumps; with the third, it varied according to the positive pressure in the water pipes; with the fourth and fifth, it was practically constant.

In Table 1 are shown the results of seven comparative tests, in which the dust collected is calculated per cubic meter of air. As a result of these tests, it is possible to state that, other things being equal, the greater the amount of air drawn in by an aspirating instrument per unit time—or the greater the negative pressure developed by the instrument—the greater is the amount of dust drawn in per unit volume of air. For dust with low specific gravity, the results do not differ so markedly as for dust with high specific gravity.[4]

In another series of tests, I found that the character of the aspiration—whether instantaneous or continuous—as well as the expiration of air at the point of inspiration, influenced the amount of dust collected. The effect of these factors, however, was too slight to merit dwelling upon at any length, although for great accuracy they should be considered.

In connection with these experiments, I wish to discuss the comparative tests conducted at Pittsburgh, Pa., under the direction of Dr. A. C. Fieldner and Dr. R. R. Sayers of the United States Bureau of Mines (3). Their committee made comparative tests of six instruments: the sugar tube, the Palmer apparatus, the paper thimble, the impinger, the Kotzé konimeter, and the Anderson-Armspach determinator. The work was carried out in the special gas chamber of the Pittsburgh station of the Bureau of Mines with various dusts (iron, grain, silica, limestone, and coal) which were put up by a special duster. These dusts were sampled simultaneously by all six instruments, the intakes of which were grouped close together.

In Table 2, I have compared the results of the gravimetric determinations made with the first four instruments (the last two are not used for gravimetric determinations). Sam-

[4] This statement holds true for thirty-three out of thirty-five samples, the discrepancy in the other two cases being attributable, I believe, to errors in sampling.

pling was begun and finished simultaneously with the four instruments, eighteen tests being made with each instrument and each test giving four separate samples.

It will be seen that dust determinations made by means of these four instruments differ considerably from each other. We cannot tell from the results to what factor these differences

TABLE 1.—COMPARATIVE DUST RECOVERIES BY THE SAME COLLECTOR, USING DIFFERENT SUCTIONAL DEVICES WITH DIFFERENT SUCTIONAL FORCES

KIND OF DUST	PETRI PUMP	BELLOWS	WATER SPRAY PUMP	BOTTLE SYSTEM	DOUBLE ASPIRATOR
	mg./cu. m.	*mg./cu. m.*	*mg./cu. m.*	*mg./cu. m.*	*mg./cu. m.*
Sawdust	182.1	106.8	84.9	95.5(?)	64.4
Chalk	158.0	104.6	79.3	68.8	23.7
Rye flour	544.7	236.0	201.6	191.3	189.8
Limestone	459.5	326.9	216.3	178.3	103.3
Tobacco	151.5	161.0(?)	98.2	78.4	76.2
Coal	290.8	231.5	108.1	102.4	71.5
Cement	261.1	151.2	74.8	61.1	56.2

TABLE 2.—COMPARATIVE AVERAGE DUST RECOVERIES BY GRAVIMETRIC DETERMINATIONS MADE WITH THE SUGAR TUBE, PALMER APPARATUS, PAPER THIMBLE, AND IMPINGER

TEST NO.	KIND OF DUST	SUGAR TUBE	PALMER APPARATUS	PAPER THIMBLE	IMPINGER
		mg./cu. m.	*mg./cu. m.*	*mg./cu. m.*	*mg./cu. m.*
1	iron	6.0	4.2	....	....
2	iron	3.7	4.9	12.1	....
3	grain	24.3	13.5	19.7	....
4	grain	30.4	18.1	24.0	....
5	silica	30.8	11.9	49.2	35.5
6	silica	22.8	15.7	30.6	26.8
7	coal	19.7	18.0	26.9	33.4
8	coal	12.6	10.9	11.2	15.2
9	limestone	1.2	2.6	3.2	2.6
10	limestone	3.4	2.4	9.7	2.1
11	grain	82.2	....	93.6	....
12	iron	10.6	6.1	13.8	8.5
13	silica	1.0	1.9	....	2.3
14	silica	−2.1	0.9	....	2.3
15	iron	−2.2	0.7	....	0.8
16	iron	−2.2	0.4	....	1.0
17	coal	−0.5	1.1	....	1.0
18	coal	2.4	....	....	....

are due, because the instruments were unlike in so many respects: thus, (*a*) the intakes of the sugar tube and the paper thimble pointed upward vertically and those of the Palmer apparatus and the impinger forward horizontally; (*b*) the intake areas of the filters in the various instruments were not the same—sugar tube = 28.6 sq. cm., Palmer apparatus = 6.4 sq. cm., paper thimble = 8.6 sq. cm., impinger = 1.6 sq. cm.—these divergences, as well as differences in the rate of air flow in the four instruments, causing the negative pressure at the intakes of the filters to vary; (*c*) the efficiency of the filters was not the same in every case, the Bureau of Mines investigators showing, in respect to silica dust, that the sugar tube retains 70 to 80 per cent. of the entire amount of dust entering the instrument, the Palmer apparatus 20 to 30 per cent., the paper thimble 81 per cent., and the impinger 93 per cent.; and finally (*d*) the results for the paper thimble include the whole amount of retained dust, whereas those for the other instruments include only the weight of dust particles under 50 microns in diameter.

Although it is not possible, therefore, to determine what factor is responsible for the different values obtained by the four instruments (see Table 2), these data confirm my opinion that the method of aspirating the air directly affects the amount of dust caught.

If we now consider the respiratory system of man, we find that he inspires intermittently, at frequent intervals, his inspiration resulting from a negative pressure of from 10 to 120 mm. of water[5] developed at the intakes of the exterior respiratory passages. Furthermore alternation of inspiration and expiration at the same point causes definite air currents. The respiratory apparatus of man, therefore, functions differently from the dust sampling instruments usually employed, and it is reasonable to assume that the amount of dust inhaled by man differs from the amount caught under similar conditions by the usual sampling instruments.

It is evident, then, that for the determination of dust inhaled by man we cannot use the first instrument we stumble upon, but that we must have at our disposal an instrument which imitates the functioning of the respiratory apparatus of man, and which has at the same time a maximum dust retaining capacity. With such an instrument it would apparently be impossible to ascertain the actual quantities of dust contained in a unit volume of air, but it would be possible to attain sufficiently correct estimations of the quantities of dust which a man inhales in unit time, estimations in which we are chiefly interested.

I suggest introducing to industrial hygiene, therefore, the term "dust coefficient" to signify the average amount of dust a workman inhales in a given workplace during an hour; this dust coefficient will vary not only in accordance with the dustiness of the air in the workroom, but also with the lung ventilation which the worker develops as a result of the work that he performs.

[5] These data for negative pressure were taken in the nasal cavity by Donders' method. The low figures refer to quiet and the high figures to forced breathing.

By expressing results in terms of this coefficient and stating the method of its determination, we should attain uniformity and agreement in dust determinations in workplaces. We could then speak of industries with high, moderate, and low dust coefficients and could draw reasonable conclusions as to the real amount of dust inhaled by a worker in a given workroom during a day, a month, or a year. Moreover, we should then be able to give the permissible or limiting coefficient for an industry depending on the toxicity or noxiousness of the inhaled dust.

In order to determine the dust coefficient in industries, it would be quite reasonable to draw air through the dust filter by means of the respiratory apparatus of man. Such a method is mentioned briefly by Lehmann (4) and by the Russian writer Arnoldov (5).

Believing that this method merited consideration, I constructed a konimeter (see Fig. 2) consisting of three parts. The first, *A*, is a glass tube 7 cm. in length and 2 sq. cm. in cross section, with its intake directed downward; the instrument is supplied with three of these tubes, each of which is provided with a ground cap, the tubes and their corresponding caps being numbered. Into each tube is put a filter. The second part of the apparatus, *B*, consists of a glass tube wider than *A* at one end and fastened at the other to two short tubes each 8 mm. in diameter. By means of the ground joints, tube *A* can be closely inserted to a depth of 2 cm. into tube *B*. The third part, *C*, consists of two nosepieces, which are cup-shaped and expand at the base; to these are attached short, bow-shaped rubber tubes, 8 mm. in diameter, which are connected by short pieces of

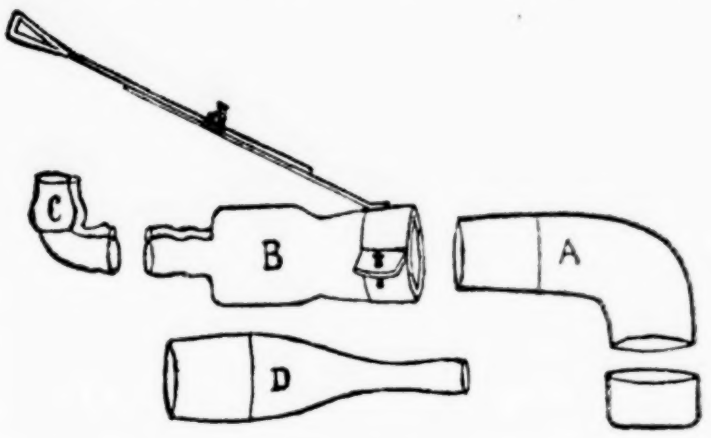

FIG. 2.—Koniogravimeter. (For *A*, *B*, etc., see description in text.)

rubber to the tubes of like diameter proceeding from *B*.[6] Thus the nostrils can be tightly closed when the nosepieces are inserted into their openings. The instrument is supplied with three pairs of nosepieces of different sizes. Tube *A* is inserted into tube *B* at the ground joint; on the top of *B* is put a thin, adjustable metal ring lined with a cloth or leather gasket, which serves to connect parts *A* and *B* rigidly. To the adjustable ring, a narrow pliable metal rod ending in a loop is attached at a sharp angle. The rod consists of two parts, sliding one upon the other. By means of a screw, these parts can be fastened in any position so that the length of the rod can be varied at will from 8 to 12 cm. The instrument is also supplied with a ribbon or band which fits around the head and has a small hook coming at the forehead. The instrument is compactly packed into a case measuring 23 by 14 by 5 cm., the total weight of instrument and case being about 400 gm.

In actual use, the procedure is as follows: After loading all the *A* tubes with a filtering substance, slightly

[6] The diameter of both sets of tubes may be greater.

grease with vaseline the interior downward surfaces of the tubes, in order to retain the dust particles which touch the walls, and dry the tubes and caps to a constant weight; then select the proper nosepieces and adjust them to the instrument, which is then ready for transportation to the place where the dust determination is to be made. On unpacking the apparatus for use, fit the ribbon or band to the forehead, connect parts *A* and *B*, tightly insert the nosepieces into the nostrils,[7] and attach the adjustable rod to the hook on the ribbon. The intake of tube *A* should always be pointed downward. With the instrument thus in place, it is necessary to inspire through the nose and expire through the mouth. Tests are carried out, on the average, for about one hour and may be made either by the experimenter himself or by some of the workmen while they are performing their usual tasks.

In the laboratory, tube *A* is dried to constant weight and the gain in weight shows the amount of dust inhaled by the workman for the time during which the test lasted. If the result is computed for one hour, we have the dust coefficient for this workroom.

Since this apparatus can be supplied with several tubes, *A*, it is possible to carry out several tests in different places in the course of one visit and thus to determine the average dust coefficient. If the dustiness in the workroom varies at different times of day, it is necessary to take samples at different hours, choosing the maximal, average, and minimal degrees of dustiness.

When the experimenter cannot take part in the work going on in the factory and when it is impossible to provide one of the workmen with an instrument, the experimenter may, before or after the test, determine the amount of air he inhaled in each breath by connecting the ground joint of the extra tube *D* to *B* and the other end to a gas meter or a spirometer. Thus, if he inspires 400 c.c. per breath and a workman under working conditions inspires 600 c.c., the results obtained by the experimenter must be multiplied by 1.5, in order to secure the amount of dust inhaled by the workman for the specified time. It is preferable, however, whenever possible, to carry out tests under actual working conditions.

I am far from holding the opinion that this konimeter will give an identical result in the hands of various experimenters; moreover, insignificant deviations are bound to occur. Nevertheless, I am convinced that, by observing the precautions to which I have alluded, reliable results may be obtained. Indeed, my colleagues and I have determined many dust coefficients in various industries by means of this instrument.

The chief advantages of the instrument are its practical utility in determining dust coefficients, its portability, and its simplicity in use. Its disadvantage lies in the fact that the experimenter must breathe through a layer of cotton wool. This causes some inconvenience and may lead to incomplete breathing, which, in its turn, may produce inaccurate results. I have been convinced, however, that a little preliminary training in the use of the instrument removes this objection.

[7] It is best to coat the nosepieces with vaseline in order to prevent leakage.

Since the term "konimeter" is generally applied in literature to an instrument for determining the number of dust particles in a unit volume of air, I have called my instrument the "koniogravimeter," meaning by this that it determines the *weight* of dust in a certain volume of air.

Several authors have suggested drawing air by mouth through a filter, but I concluded, after repeated experiments, that this method was useless for the following reasons: In order to insure mouth breathing, it is necessary to use a nose clip. This clip, in turn, must be loosened to permit exhalation through the nose and fastened to permit inspiration again through the mouth, or both expiration and inspiration must take place by mouth. Either procedure is inconvenient and may lead to inaccurate results.

In addition to the koniogravimeter, a pump may be used which is of variable capacity and is connected to a filter of the required size with intake directed downward. By means of such an arrangement, one may work the pump in fair imitation of the respiratory apparatus of the workman in the factory. Thus, if a workman inhales 600 c.c. of air in one breath, the pump is adjusted to draw this amount at each stroke. The number of strokes per minute is, of course, important and the experimenter must follow, as closely as possible, the rhythm of his own breathing or that of the subject under study. The amount of dust retained on the filter will then correspond to the average amount which the workman inhales in a like volume of air.

The calculation of the dust coefficient in a workroom is best illustrated by an example: Let the average amount of air inhaled by the workman in an hour equal 500 liters; the pump is fixed at 500 c.c., the total number of strokes on the pump is 1,200, and the increase in weight of the filter is 30 mg. The dust coefficient will then be

$$\frac{30 \times 1{,}000 \times 500}{500 \times 1{,}200} = 25 \text{ mg.}$$

A pump fulfilling the foregoing specifications was constructed under my personal direction by M. N. Gasteff, manager of the power station of the Odessa Medical Institute. It is shown, connected to a filter, in Figure 3. *A* is the cylinder of the pump, *B* the intake, *C* the exhaust—both openings being provided with ball valves—*D* is the rod of the pump and is connected with scale *E*. A movable collar *G* is attached to the scale and fixed with a screw at the required height. When the piston is lifted, the collar hits against the immovable plank *F* and thus the length of the stroke is regulated. The lower the collar is fixed, the higher the piston may be raised at every stroke, and *vice versa*. Before beginning a test, the collar is fixed at such a point that the average volume of air, in cubic centimeters, corresponds to the amount of air inhaled by the workman in one breath. Every knock of the collar against plank *F* (showing that a full stroke has been taken) is easily felt by the experimenter and is registered by a calculator *K*.

If it seems desirable to imitate more closely the respiratory apparatus of man, the exhaust air from the pump can be blown back to the point of inspiration, as indicated in Figure 3. Although it is possible to lead the

expired or exhausted air through the same opening used for inspiration, a it conforms well with the human respiratory apparatus.

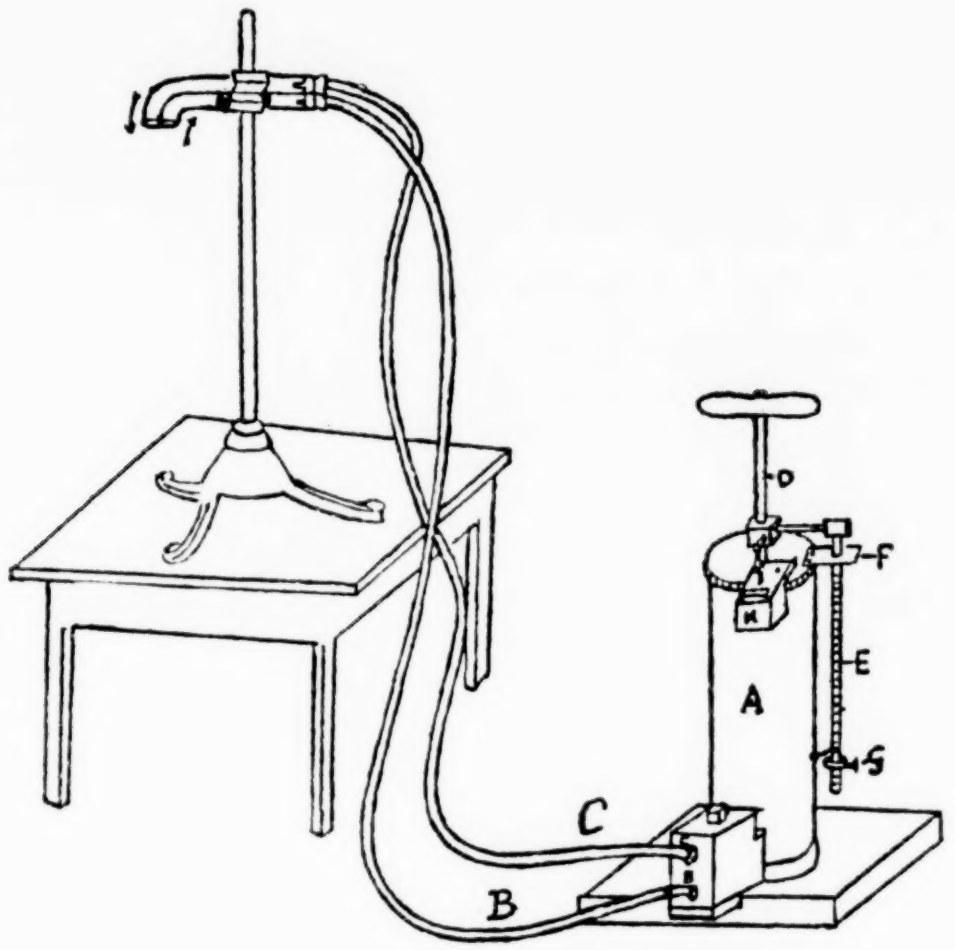

FIG. 3.—Pump used for determining dust coefficient. (See text.)

part of the retained dust may thus be lost; I have, therefore, led the exhaust stream to a point close to the intake.

When the pump is adjusted for capacities of from 400 to 1,000 c.c. and is operated at speeds corresponding to the rhythm of human respiration, it is found that a negative pressure of from 10 to 140 mm. of water and a linear air velocity of from 18 to 38 cm. per minute are developed.[8] When it is considered that the instrument is connected with a filter the intake of which corresponds to the nostrils of man in size and in position and that it expires immediately after it inspires, it would seem that, for our purposes,

[8] The air velocity at the intake of the filter was determined by means of Hill's kata-thermometer.

The capacity of the pump need not be arbitrarily fixed, because the average quantity of air inhaled by a workman in a given room may easily be determined with the aid of a gas meter or a spirometer. Moreover, it would not be difficult to work out a suitable table which the investigator could then apply.

The weight of the pump with all its accessories, together with the case, is 12 kg.; the size of the case is 24 by 26 by 158 cm. Its advantages have already been pointed out; its disadvantages consist in its weight and in the fact that it is arranged only for hand power and that the intake and exhaust air do not pass through the same opening. Except for the last disadvantage, which is inessential,

these difficulties can be remedied; the pump can be made lighter and adapted to either hand or electric power. If, at the same time, a table is worked out for depth and rhythm of breathing of workmen at different tasks, we should then have an ideal physiologic aspirator.

Finally, in order to determine the dust coefficient, one can use as an aspirator bellows that are made absolutely air-tight and so fitted that their capacity is variable. A model of such bellows was made for me by M. N. Gasteff, but I shall not describe it in detail.

In order to compare the action of the pump and the koniogravimeter, I made determinations of the dust coefficient simultaneously with both instruments. From the results, which are shown in Table 3, it is seen that the koniogravimeter gave consistently lower coefficients than the pump—an average difference of 2.2 per cent. I believe that this difference is due to the fact that a subject experiences some difficulty in breathing for one hour through a layer of cotton wool, as has been previously pointed out.

TABLE 3.—DUST COEFFICIENTS IN VARIOUS INDUSTRIES

NAME OF INDUSTRY	DUST COEFFICIENT DETERMINED		DIFFERENCE	
	Pump	Koniogravimeter		
	mg.	*mg.*	*mg.*	*%*
I State Leather Factory (bark crumbling division)	16.2	15.9	0.3	1.8
II State Mill (dust chamber)	48.7	47.9	0.8	1.6
I State Tobacco Factory (cutting division)	36.2	35.7	0.5	1.4
I State Jute Factory (preparing division)	27.1	26.4	0.7	2.6
I State Machine Factory (casting trade)	7.1	6.9	0.2	2.8
I State Machine Factory (molding division)	14.3	13.9	0.4	2.8
Average				2.2

In regard to the filtering substance, there is no doubt that for industrial field work it is more convenient to employ solid filters than to use distilled water. Laboratory work on the solid filter—drying it to constant weight and weighing it—is easier than that necessitated by the wet method, which consists in transferring the water containing dust into a beaker, washing out the dust with distilled water, and reweighing the solid residue. Moreover, to transport a dry filter from the field to the laboratory is easier than to transport a vessel filled with liquid. Parallel tests made with solid filters and with distilled water gave very similar results.

For a solid filter, in my opinion, it is better to use glass wool rather than cotton wool, because the latter is very hygroscopic and does not remain long at constant weight; in fact, even while it is being weighed, a cotton wool filter sometimes takes up from 2 to 3 mg. of moisture and is therefore use-

less in cases where the increase in weight of the filter due to dust is slight. Portions of the glass wool filter, on the other hand, are sometimes carried away by the air current. To obviate this difficulty, the filter may be furnished with a fine brass screen on the side nearest the aspirator (6), or a very thin layer of cotton wool may be wrapped around the end of the glass filter nearest the outlet. The moisture absorbed by this thin layer of cotton wool is insignificant.

The filter for the koniogravimeter must not be so thick as to make breathing difficult. With the slight negative pressure developed by the human respiratory apparatus, a filter 1.5 to 2 cm. thick is sufficient to prevent dust from passing through. Thicker filters may be used with the pump.

I checked the dust retaining capacities of glass and cotton wool filters by the method of Arens (2) and Aitken (7) and I could not find that dust passed through a well-made filter. I intend to make further tests by Tyndall's method, as used by the American investigators. Should we permit any very small dust particles to pass through the filter—such particles as Gibbs (8) classifies as "smokes"—the weight of the dust lost would be too slight appreciably to affect the results.

In drying the filter to constant weight, it is best to use an oven heated to 105°C. and subsequently to cool the filter in a desiccator over strong sulphuric acid.

The flexible rubber tubes for the pump or bellows should not be more than 1.5 to 2 meters long on the average, nor should the diameter of the cross section be less than from 10 to 12 mm.

In conclusion, of the instruments I have proposed for determining the dust coefficient in industry, I prefer the pump to the koniogravimeter because it is easier and more convenient for the experimenter to manipulate. These instruments have now been installed in several laboratories and I hope to receive reports on their practical utility at the next conference of industrial hygienists. Those from whom I have already heard report good results.

Summary

1. The methods usually employed in the gravimetric determination of dust in air do not give accurate results, because they indicate the amount of dust in the volume of air that passes through the filter, but not the amount of dust in the air of the workplace under study.

2. Comparative tests of the same filter show that, other things being equal, the amount of dust retained depends on the negative pressure developed at the intake of the filter and on the direction or position of the intake.

3. The greater the negative pressure at the intake, other things being equal, the greater is the amount of dust inspired into the filter. As the particles decrease in size or their specific gravity changes, the effect of varying the negative pressure on the aspirator becomes still more pronounced.

4. When the intake of the filter points vertically downward, the amount of dust retained seems to be

less than when the intake points horizontally. With small negative pressures at the intake of the filter and with dust particles of different sizes, the amounts of dust caught when the intake of the filter is in different positions are found to vary markedly.

5. Calculations of the amount of dust which a man inhales in a given time, based on data from gravimetric dust determinations, are accurate only when the dust sampling apparatus closely imitates the functioning of the human respiratory apparatus.

6. Since it is possible to determine the amount of dust which a man inhales in unit time, it is desirable to introduce into industrial hygiene the term "dust coefficient" to signify the average amount of dust inhaled by a workman during an hour in a given workroom.

7. The koniogravimeter described in this paper, as well as the pump and bellows, used in connection with an appropriate filter, may provide useful methods for determining the dust coefficient in industry.

In conclusion, I wish to express my sincere thanks to Prof. N. N. Kostiamin and Dr. M. L. Levontin for their co-operation in the course of this work, and also to Dr. A. D. Shtchigoleff, Dr. S. V. Volter, Dr. I. I. Feldman, and Dr. D. I. Lass for their assistance in conducting my studies.

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BOOK REVIEWS

THE ALCOHOL PROBLEM. By *H. M. Vernon*. With a preface by Viscount D'Abernon. Pp. 252 with index; illustrated. London: Baillière, Tindall & Cox, 1928.

The claim is made in the preface that British war time experience proved that intemperance could be controlled by skilful legislation and also that today control is urgently required. Then the author states the problem, showing that, while alcoholism is impairing industrial efficiency and is costing from a fifth to a fourth of the family budget to the detriment of improved housing, more food, and better clothes, the progress of temperance reform is slow, and there is no single path to success. The development of complete prohibition in the United States is described and its effect on alcohol consumption, on drunkenness, mortality, and crime; the results, although much has been achieved, are not such as to recommend any other country to follow along the same path. Moreover, the small scale prohibition experiment of Finland has produced effects closely similar.

The story is next told of how partial prohibition in many forms and guises has been experimented with in Canada, Australia, New Zealand, Sweden, Norway, and other countries. In each case, if legal restriction has gone ahead of public opinion, the law has been fiercely fought and the tide of temperance has ebbed. Various measures of control were adopted in England during the war; first came military restriction of hours of sale; next the beer duty was trebled; in May, 1915, the Liquor Control Board came into action issuing regulations for different areas, limiting hours of sale, diluting spirits, prohibiting off sales at week-ends and stopping "treating;" later, supplies were reduced to save grain, and finally duties on beer and spirits were again raised. The curve exhibiting the effect in reducing the amount of alcohol consumed and convictions for drunkenness is one of the most illuminating things in this book. It shows also how, with modified limitation of the hours of sale and raised duties on spirits, much of the ground won in war time has been held in succeeding years. The scientific basis of the war time regulations is stressed, with regard to making it difficult to get drink before taking food and to get it in concentrated form. Moreover, the "drunkard's hour," between 10 and 11 P.M., was closed down. Of the two factors, high taxation and reduced hours of sale, the latter is the more important; but both can be regulated on a physiologic basis. Favorable reference is made to the value of disinterested management of public houses, and to the state experiment in the Carlisle area which is held to be giving good results, economically and socially.

Dr. Vernon then turns to discuss the effects on efficiency of moderate amounts of alcohol, quoting experiments of his own; all evidence points to alcohol's being a sedative and nar-

cotic drug which acts chiefly on the nervous system. It slackens reticence, self-criticism, deliberation, and judgment; and the higher the type of work, the greater is the influence of the drug. If, however, alcohol is taken with food or well diluted, the intoxicating power is greatly lowered. Attention is particularly directed to the question of dilution, and upon this foundation is built a scientific scheme of differential taxation. This scheme is drawn up on the basis of maintaining the total raised from the taxation of alcohol. According to it beverages would be taxed according to the percentage of alcohol by volume, thus:

Liquor	*Tax in Pence for Each Per Cent. of Alcohol*	
	Under Scheme	*Now*
Very weak beer	1.4	3.4
Weak beer	2.9	3.9
Average beer	4.3	4.3
Strong beer	5.8	4.7
Claret	7.0	3.5
Port and sherry	9.6	4.8
Spirits at 60° under proof	10.5	15.2
Spirits at 30° under proof	20.0	

One merit of this scheme, says Lord D'Abernon, is that it can be introduced at any time, either in stages or in a complete form, and it might at once begin to exert some influence in promoting sobriety. The value of sobriety is exhibited from mortality statistics which are heavily against immoderate drinking. But moderate drinking from the actuarial standpoint remains uncondemned; quite different is its position with regard to occupational efficiency. Here, taking industry all through, the total reduction in efficiency produced by the consumption of alcohol is placed at something like 10 per cent.

The impression which this book gives is that it is written in a scientific spirit by one who desires only to place facts in their right setting, free from the bias of the religious abstainer on the one side or of the trade on the other. Possibly for this very reason it will fail in its object by falling between two stools.—*E. L. Collis.*

SAFETY AND PRODUCTION. AN ENGINEERING AND STATISTICAL STUDY OF THE RELATIONSHIP BETWEEN INDUSTRIAL SAFETY AND PRODUCTION. A Report by the American Engineering Council. Cloth. Pp. 414 with appendixes and index. New York and London: Harper & Brothers, 1928.

The safety movement, started some sixteen years ago, has had beneficial and significant effects on the frequency and severity of industrial accidents in the United States. "In many industrial establishments accidents have been cut a half or three-quarters or even more." In recent years, however, there has been an increase in the number and severity of accidents. This has occurred during a period of increased production and rate of production. The question may well be asked, Does the speeding up of industry necessarily result in an increase in industrial accidents? In other words, is there a negative relation between safety and production?

This report is an engineering and statistical study of the relation between safety and production, undertaken in an endeavor to answer the foregoing question. Although it was impossible to study the entire field of American industry, the volume of data secured covers an appreciable part of

it. Usable information was obtained from 13,898 companies, representing 2,464,413 employees, or 54,430,707,000 man-hours.

The report is presented in three parts. In Part I a summary and digest of the investigation is given together with an excellent introductory statement of the problem by Mr. Albert W. Whitney. The second and third parts deal with detailed investigations of separate industries.

During the course of the study the following questions were raised:

1. Have industrial accidents under the conditions of intense production of the past few years increased (a) in frequency (b) in severity?
2. Are these increases in the frequency and severity of industrial accidents proportionately greater or less than the increase in production?
3. Can industrial accidents be controlled under modern conditions of production?
4. If so, how?
5. Does safety interfere with production?
6. Does a positive correlation exist between safety performance and the efficiency of production?
7. Is the safe factory the efficient factory, and the efficient factory the safe factory?
8. Is safety an executive responsibility? Is the key to the new safety movement the executive?
9. What degree of improvement can be made in safety performance? What reduction can be expected in the costs of industrial accidents?

The answers to these questions are found in the analysis of the data collected and are summarized in the findings of the Committee:

1. Industrial accidents can be controlled under modern conditions of highly efficient productivity.
2. The rate of change in production per man-hour for the industrial groups studied is greater than the rate of change in accident frequency per man-hour or the rate of change in accident severity per man-hour. . . . .
3. . . . . material reductions in accident rates can be obtained simultaneously with increase in production rate.
4. Major industrial executives have as much responsibility to initiate accident prevention as to initiate improvement in productivity.
5. Efforts to improve safety performance do not interfere with production.
6. Maximum productivity is ordinarily secured only when the accident performance tends toward the irreducible minimum.
7. The production and accident performances of the best plants in each industry studied clearly show that tremendous improvements can be achieved by the majority of plants in each industry.
8. The incidental or accompanying cost of industrial accidents is a loss in industrial operation which should not be neglected.
9. Organized safety work is being carried on in a relatively small percentage of industrial plants.
10. A large number of industrial establishments keep no accident records and make no attempt to analyze their experience as the first step in decreasing accidents.

This report is a valuable contribution to the literature dealing with the relation of the worker to his environment. It is gratifying to know that, in the face of intensified production, it is possible to control this one factor in the industrial environment.

Of particular importance is the conclusion of the Committee that accident prevention work is a responsibility of major executives. It is to be hoped that executives in greater numbers will accept this responsibility.—*Theodore Hatch.*